FOUR YEARS (2018-2021) MONITORING OF SEEDLING RECRUITMENT BEFORE AND AFTER RAT ERADICATION ON MOTU REIONO, TETI'AROA ATOLL (SOCIETY ISLANDS)

by

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Background and objectives

The goal of this study was to conduct a multi-years monitoring of plant seedling recruitment (mainly native and woody species) in permanent transects and quadrats set up in the atoll of Teti'aroa (MEYER 2018) before and after a rat eradication operation (SAMANIEGO *et al.* 2020) in order to study forest dynamics during this ecological restoration project, and to try predict the ecosystem successional trajectory.

Material and methods

Study site

Motu Reiono (ca. 22 ha) is the southernmost « motu » (sandy islet) of the coral atoll of Teti'aroa located in the Society Islands, French Polynesia (**Fig. 1**). It was inhabited in the past by Polynesians, as evidenced by the presence of several archeological structures, including a temple (« marae Apara »), meeting houses (« fare pote'e ») and an archery platform (MOLLE *et al.* 2019). The motu was then temporary occupied during the European period with a coconut trees plantation set up in the 1950's (according to aerial photographs). The current vegetation is relatively intact with a the vascular flora composed of 15 native species and five naturalized alien plants including *Cocos nucifera* and Polynesian introduced trees such as *Morinda citrifolia* (« noni »), *Barringtonia asiatica* (« hotu »), *Talipariti tiliaceum* (syn. *Hibiscus tiliaceus*, « purau »), *Thespesia populnea* (« miro »), and few seedlings of the invasive mangrove *Rhizophora stylosa* which were removed (MEYER 2018).

Figure 1. Satellite image of Motu Reiono (Pleiades 2014, © IDEA-ETH Zurich) with the location of the 10 study plots (courtesy of Benoît STOLL, Université de la Polynésie française).

Permanent transects, quadrats, and circular plots

An experimental protocol, inspired by a similar study (WOLF *et al.* 2018) conducted in the 230 ha uninhabited atoll of Palmyra in the Northern Line Islands (North Pacific) during a previous rat eradication project, was used in Reiono: we set up 25 m long x 2 m large transects (*i.e.* a total area of 50 m²), marked on its median line and at both ends by iron posts, tagged with color flags indicating the transect number (TR1 to TR10). Each transect was divided into fifty 1 x 1 m quadrats located on both side (right and left) of the median line (**Fig. 2**). The « start post » and « end post » were georeferenced with a GPS (Garmin Map 64s) and direction from start post to end post was assessed with a compass.

In each of the 50 quadrats, the total number of seedlings (< 30 cm in height) was counted for each woody plant species, as well as coconut « seedlings » (*i.e.* germinating coconuts with 1 to 6 small leaves). Resprouts (*i.e.* small stems with leaves) from roots were not counted, as well as coconuts without any leaves (*i.e.* young and full of water, or opened and empty, or dried and dead).

A total of 10 transect was set up in the interior of the motu (**Fig. 1**), representing a sampled area of 500 m², in different forest types. Transects were not selected in plant habitats located at the periphery of the motu, such as dense shrublands of *Scaevola taccada* (« naupata ») and *Suriana maritima* (« 'o'uru ») and low canopy forest of *Heliotropium foertherianum* (« tāhinu ») to avoid both forest edge effects and the impacts of seawater on seedling survival. We have also avoided *Pisonia grandis* (« pu'atea ») forests with an understorey dominated by the large terrestrial fern *Asplenium nidus* (« 'o'aha ») where it was too difficult to set up quadrats.

In order to better characterize the different plant habitats/forest types, we have set up 25 m diameter circular plots (CR1 to CR10) centered around the transects (*i.e.* with an area of about 490 m²). The total sampled area of 4900 m² (0.49 ha) represents about 2% of the land surface of Motu Reiono (**Fig. 2**). The number of standing trees and their number of trunks and stems with a diameter at breast height (DBH, taken at 1,30 m from the ground) above 10 cm were counted and their diameter (or circonference) measured. The total basal area (BA in cm²/m² or m²/ha) for each species based on the surface (s) of all its individuals (i), and for all species were calculated as followed:

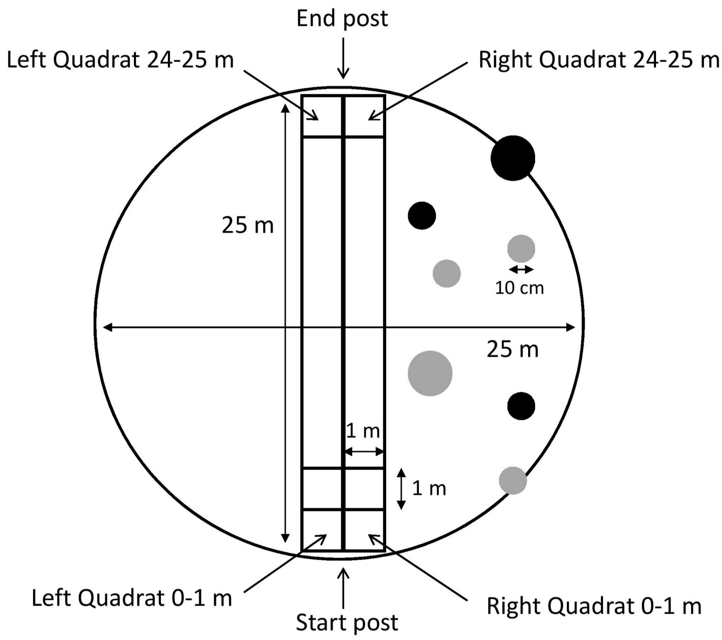
$$s = \frac{\pi \times DBH^2}{4} \qquad BA = \frac{\sum_i s_i}{490}$$

The percentage of basal area for each species (%BA) was assessed to identify the dominant species in relation to their cover.

Monitoring dates and period of survey

We started our study in July 2018, one month before the rat eradication campaign of August 2018 (SAMANIEGO *et al.* 2020) until July 2021, representing a four years monitoring period. Post-eradication surveys were conducted in June, July or August during the dry and cool season in the Society Islands in order to avoid seasonal variability in seed germination and seedling recruitment caused by heavy rains during the warm and rainy season (between November and March). Due to the covid-19 sanitary crisis that hit French Polynesia in the mid-2020, no field trip was organized between June and July, but we were able to collect some data in January 2020 when we set up the circular plots and measured tree species basal areas, and a few more in August 2020 (DEFILLION 2020).

Figure 2. **Diagram showing the circular plots (CP) centered in the middle of the permanent transect (TR).**



Results

A total of 323 trees (representing 417 trunks and stems) were counted and their diameter measured in the 10 circular plots, representing a total basal area of 662 cm²/m². The density reaches about 660 trees/ha in the sampled area (**Tab. 1**). The two most common trees are *Pisonia* and *Cocos*, followed by *Guettarda speciosa* (« tafano ») and *Pandanus tectorius* (« fara »), with few *Heliotropium*. It is notheworthy that the abundance of *Pandanus* seemed to be underestimated using the BA method because of its more slender trunks.

Table 1. **Forest composition and woody species cover in the circular plots according to the number of trees and stems (DBH > 10 cm) and Basal Area (cm²/m² or m²/ha).** Piso.= *Pisonia grandis*; Coco. = *Cocos nucifera*; Pand. = *Pandanus tectorius*; Guet. = *Guettarda speciosa*; Helio. = *Heliotropium foertherianum*.

Circular plot	Number of trees	Number of stems	Total Basal Area	BA Piso.	BA Coco.	BA Pand.	BA Guet.	BA Helio.
CP1	23	38	70,65	68,96	1,69	0	0	0
CP2	28	38	94,50	80,44	14,06	0	0	0
CP3	30	40	59,64	57,23	2,42	0	0	0
CP4	31	32	64,72	19,35	45,36	0	0	0
CP5	40	50	41,04	23,74	3,66	3,78	3,45	6,42
CP6	43	50	100,50	91,72	8,78	0	0	0
CP7	33	45	73,90	62,16	9,14	0	2,60	0
CP8	31	43	32,83	18,70	4,63	5,43	4,08	0
CP9	31	40	47,73	39,32	6,21	0	2,20	0
CP10	33	41	76,67	42,74	33,93	0	0	0
Total	**323**	**417**	**662,18**	**504,36**	**129,88**	**9,21**	**12,33**	**6,42**
Density/ha	659	851	-	-	-	-	-	-

In Palmyra atoll, only three types of forests were recognized according to the coconut tree cover based on adult basal area: « *High Cocos* » (>75% of the total basal area), « *Low Cocos* » (<25%) et « *Intermediate Cocos* » (between 25-75%) (YOUNG *et al.* 2010, WOLF *et al.* 2018). We used a forest classification based on the %BA for each woody plant taxa (**Tab. 2**) allowing us to describe the different forest types in a more quantitative and detailed way than visually (*e.g.* MEYER 2018). Results indicate that there were only two replicates for the « *Pisonia* dense forest with *Cocos* very rare » (TR1 and TR3) and the « *Pisonia* dense forest with *Cocos* uncommon » (TR2 and TR7) forest types, the six other plots being different in their composition and tree cover (**Tab. 3**).

Table 2: Forest classication according to the % basal area of each taxa with main types.

Forest type	**%BA of taxa**
Forest dominated by X (« *X dense forest* »)	X>75%
Forest codominated by X and Y (« *X-Y dense forest* »)	30%<X<75% and 30%<Y<75% and X-Y<10%
Mixed forest dominated by X (« *Mixed X forest* »)	30%<X<75% and X> all other taxa
Mixed forest dominated by X with Y (« *Mixed X forest with Y* »)	Y>25% and X-Y>10%
With Z uncommon	10%<Z<25%
With V rare	5%<V<10%
With W very rare	W < 5%

Table 3. Description of the different habitat/forest types based on forest classification.

Plot/Transect	**Habitat/forest type**
CP1/TR1	*Pisonia* dense forest with *Cocos* very rare
CP2/TR2	*Pisonia* dense forest with *Cocos* uncommon
CP3/TR3	*Pisonia* dense forest with *Cocos* very rare
CP4/TR4	Mixed *Cocos* with *Pisonia*
CP5/TR5	Mixed *Pisonia* forest with *Heliotropium* uncommon and *Pandanus, Cocos, Guettarda* rare
CP6/TR6	*Pisonia* dense forest with *Cocos* rare
CP7/TR7	*Pisonia* dense forest with *Cocos* uncommon
CP8/TR8	Mixed *Pisonia* forest with *Pandanus, Cocos, Guettarda* uncommon
CP9/TR9	*Pisonia* forest with *Cocos* uncommon and *Guettarda* rare
CP10/TR10	*Pisonia-Cocos* dense forest

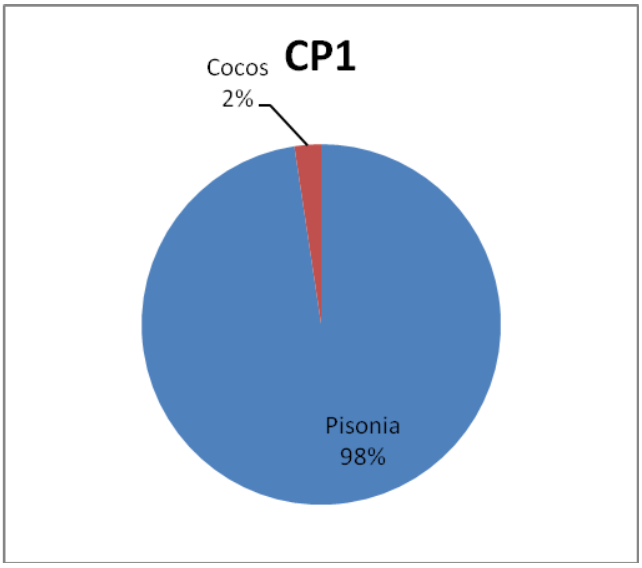
During the study period (2018-2021), seedlings of four woody species were recorded in the quadrats and transects (**Fig. 3-12**): the introduced *Cocos nucifera* and the native trees *Pisonia grandis*, *Pandanus tectorius*, *Guettarda speciosa*. We have also counted seedlings of the native climbing vine *Ipomoea violacea* (syn. *I. macrantha*, « pohue tahatai ») in two transects (TR8 and TR9). No seedling of the tree *Heliotropium foertherianum* was observed in the ten transects.

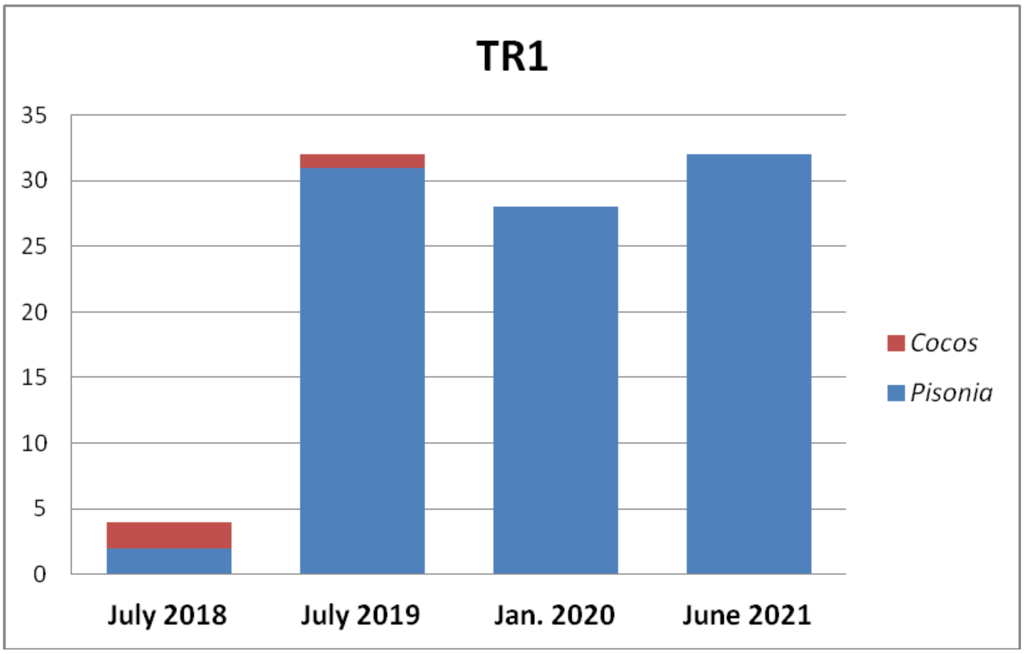
As expected, seedling recruitment differs according to forest types, with more *Cocos* seedlings found in mixed *Cocos* forest, more *Pisonia* seedlings in dense or mixed *Pisonia* forest, and *Pandanus* seedlings only in mixed forest with *Pandanus*. An increase of *Pisonia* seedling was observed in *Pisonia* dense forests before and after rat eradication (TR1 see **Photo 1**, TR2 see **Photo 2**, TR3, TR6, TR7), as well as *Cocos* seedlings in mixed *Pisonia-Cocos* forests (TR2, TR4 see **Photo 3**, TR6 see **Photo 6**).

The dramatic increase in *Pisonia* seedlings observed in TR7 (raising from about 380 in 2018 to more than 1050 in 2019) can be explained by a treefall gap near the transect (a large *Pisonia* fallen tree, see **Photo 5**), and the sudden decrease in TR5 (see **Photo 4**) and TR8, both located on the southern tip of Motu Reiono, by coastal flooding caused by a high tide or a strong swell.

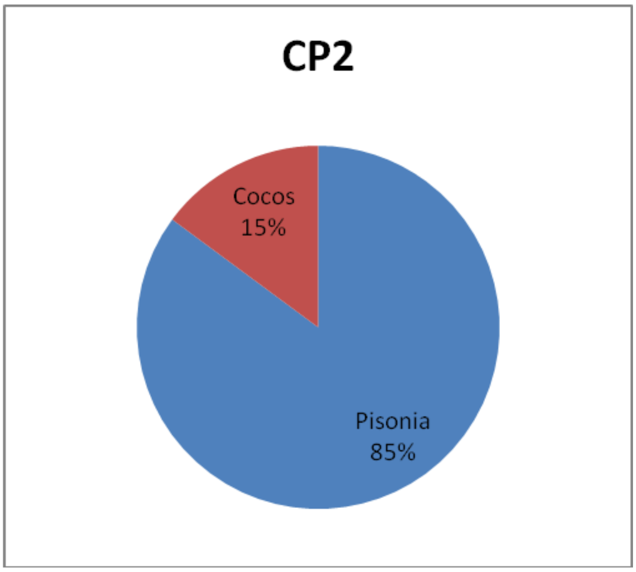
Few *Guettarda* seedlings appeared lately in 2020 and 2021 in one mixed forest with many *Guettarda* trees (TR8), but none were observed in the other transects with few *Guettarda* trees (TR5 and TR9).

Figure 3. **Forest composition and woody species cover (%BA) in circular plot CP1, and evolution of the seedlings number in permanent transect TR1 between 2018 and 2021.**





<u>Figure 4.</u> Forest composition and woody species cover (%BA) in circular plot CP2, and evolution of the seedlings number in the permanent transect TR2 between 2018 and 2021. *Many broken branches found on the ground probably related to strong winds.



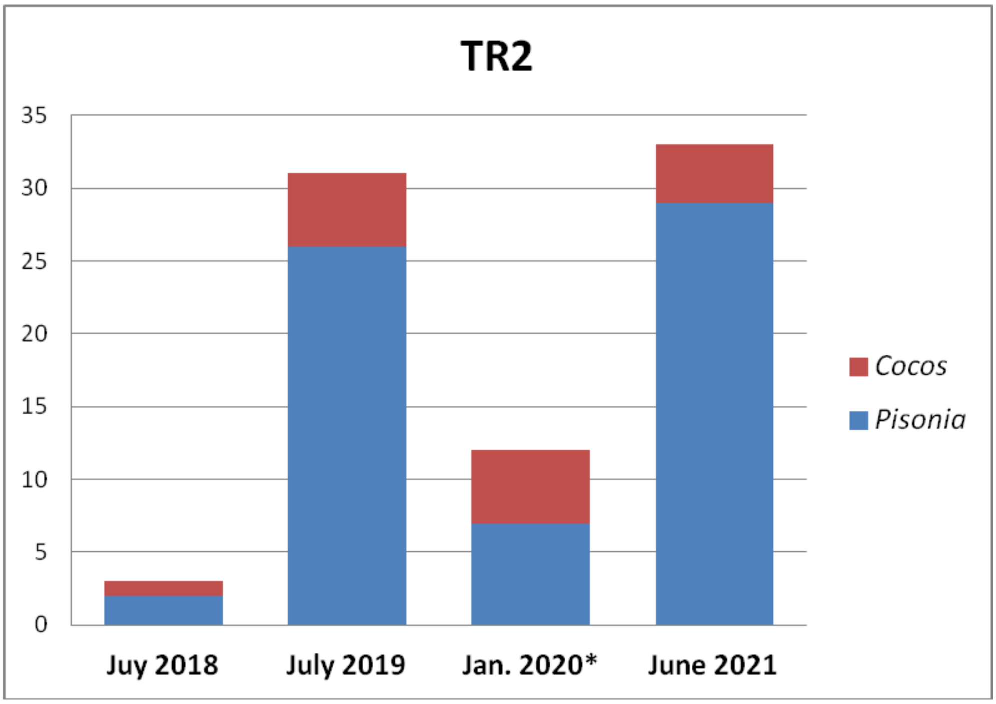
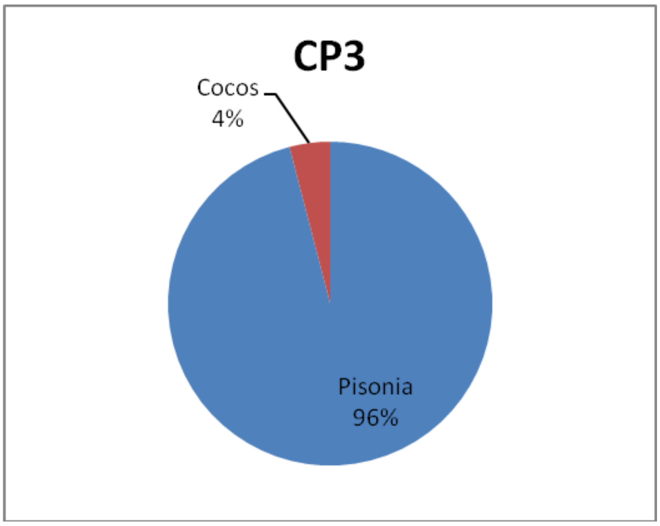


Figure 5. Forest composition and woody species cover (%BA) in circular plot CP3, and evolution of the seedlings number in the permanent transect TR3 between 2018 and 2021.



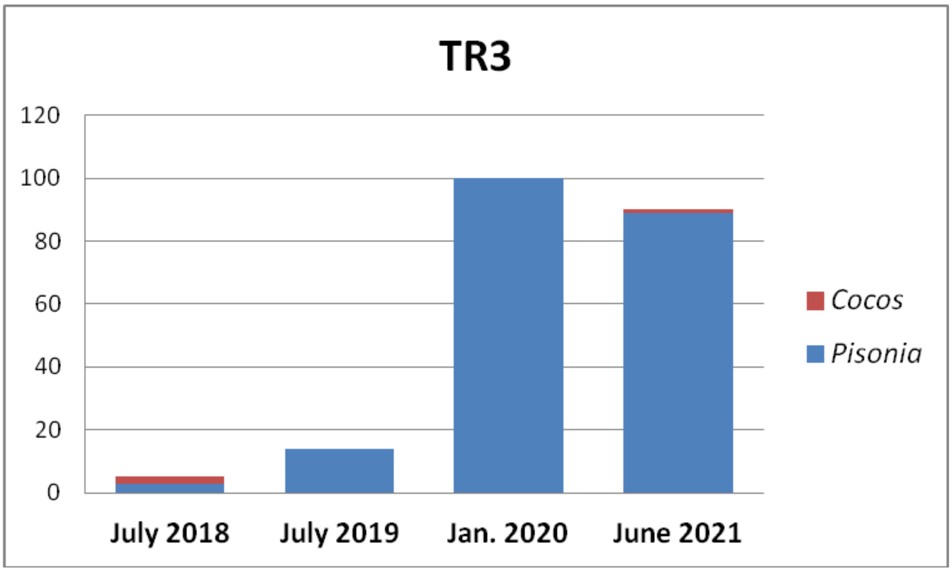
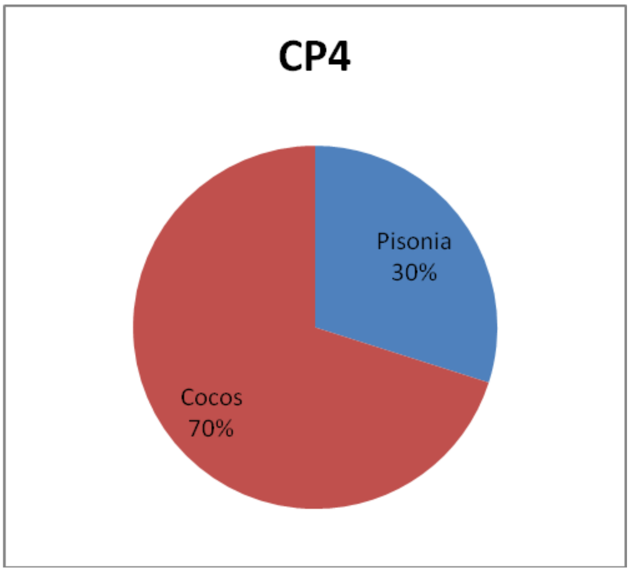
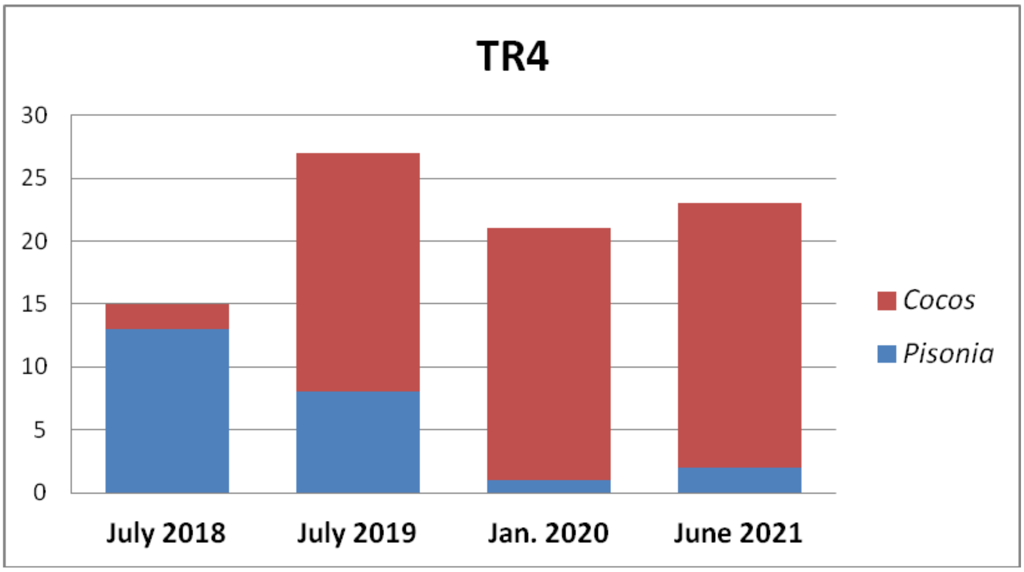
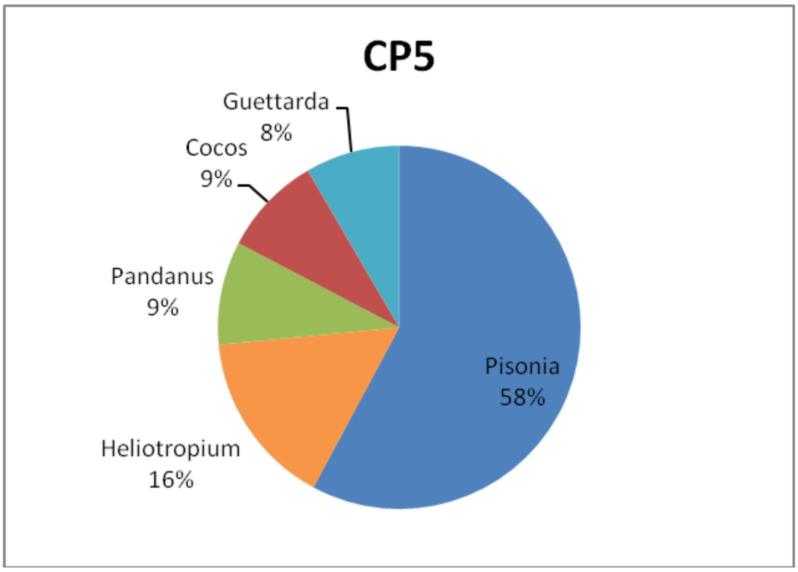


Figure 6. **Forest composition and woody species cover (%BA) in circular plot CP4, and evolution of the seedlings number in the permanent transect TR4 between 2018 and 2021.**





<u>Figure 7.</u> Forest composition and woody species cover (%BA) in circular plot CP5, and evolution of the seedlings number in the permanent transect TR5 between 2018 and 2021. ‡Passage of a high tide or strong swell on the transect.



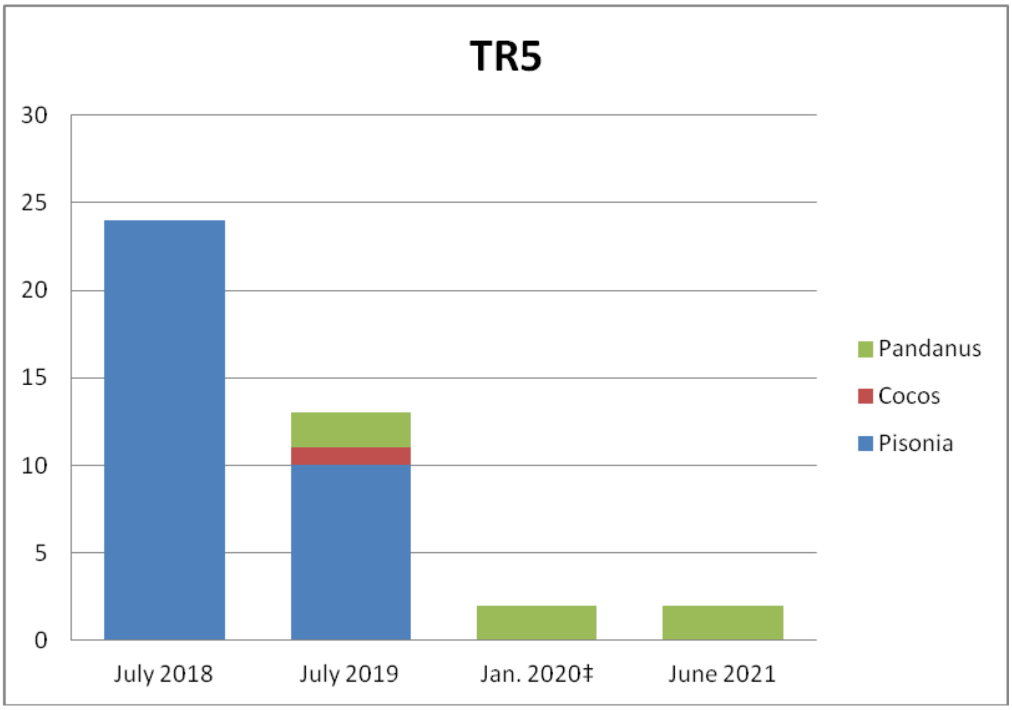
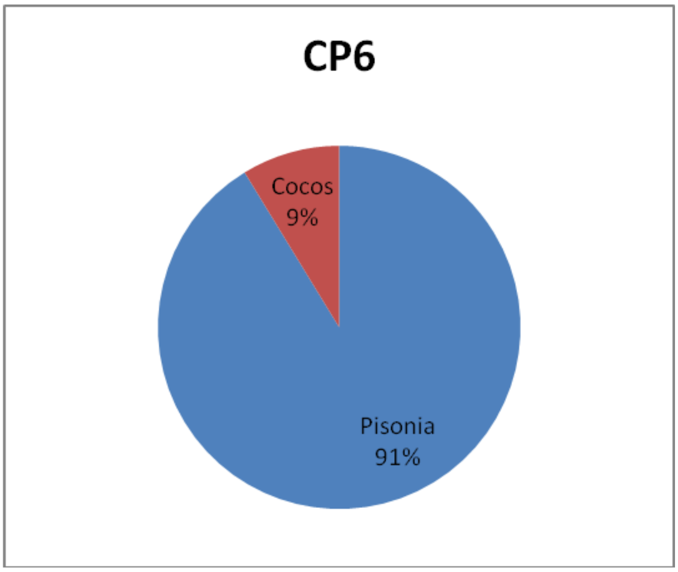
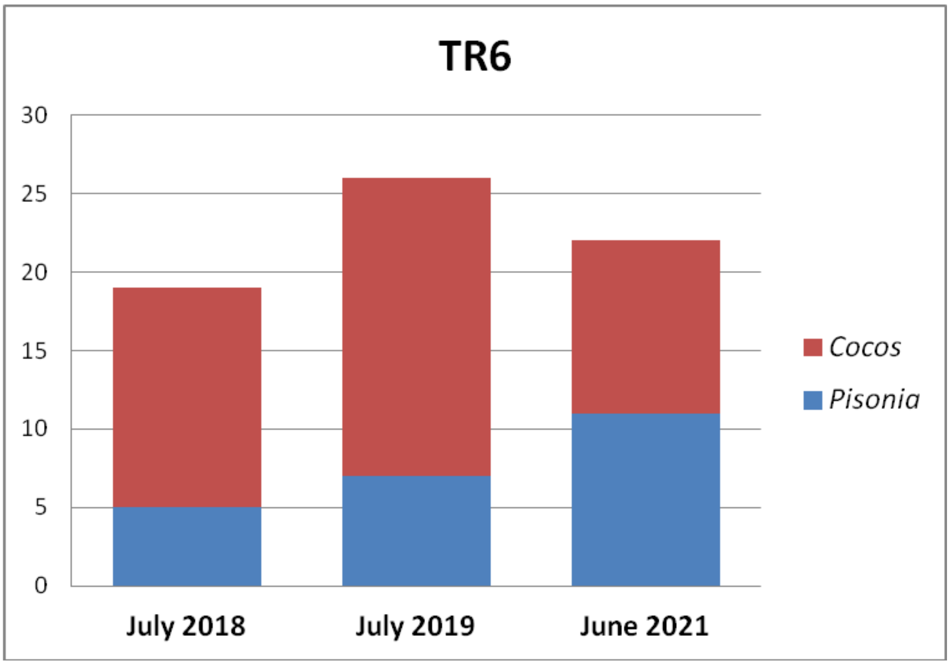
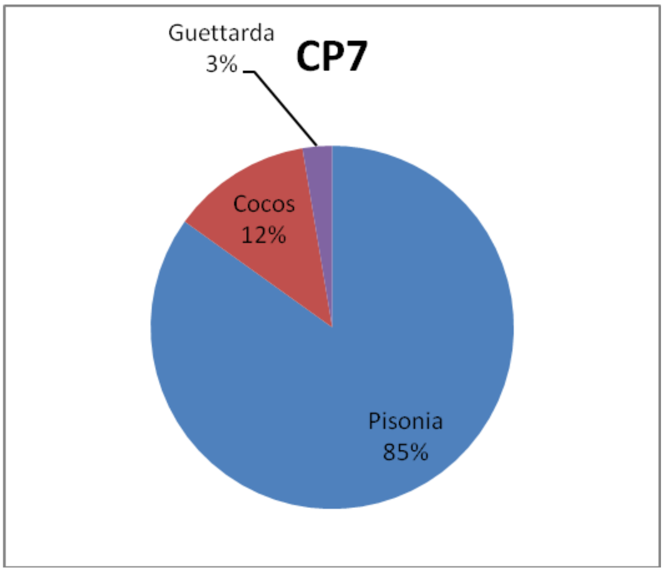


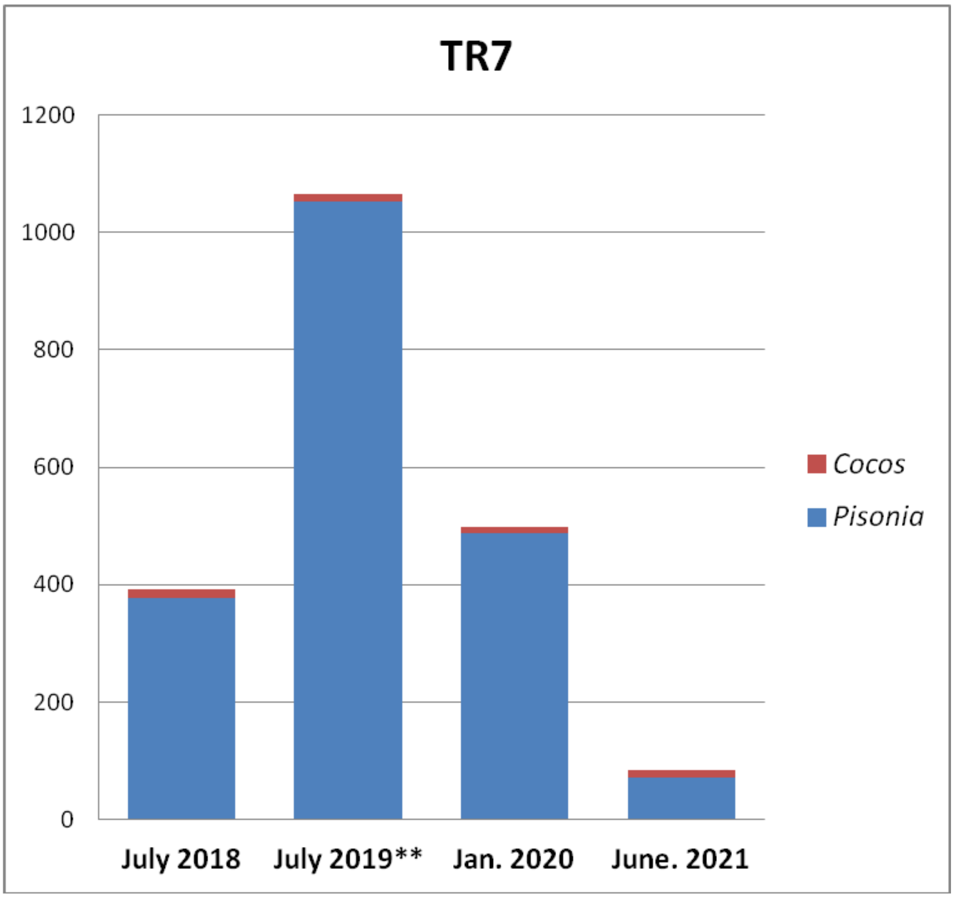
Figure 8. Forest composition and woody species cover (%BA) in circular plot CP6, and evolution of the seedlings number in the permanent transect T6 between 2018 and 2021.



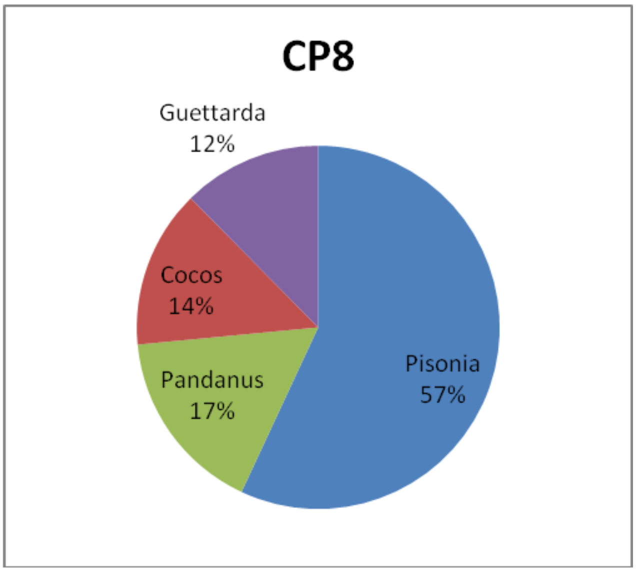


<u>Figure 9.</u> Forest composition and woody species cover (%BA) in circular plot CP7, and evolution of the seedlings number in the permanent transect TR7 between 2018 and 2021. **Treefall gap (a fallen *Pisonia* tree nearby the transect).





<u>Figure 10.</u> Forest composition and woody species cover (%BA) in circular plot CP8, and evolution of the seedlings number in the permanent transect TR8 between 2018 and 2021.**Treefall gap (a fallen *Pisonia* tree near the transect) and the signs of the passage of a high tide or strong swell.



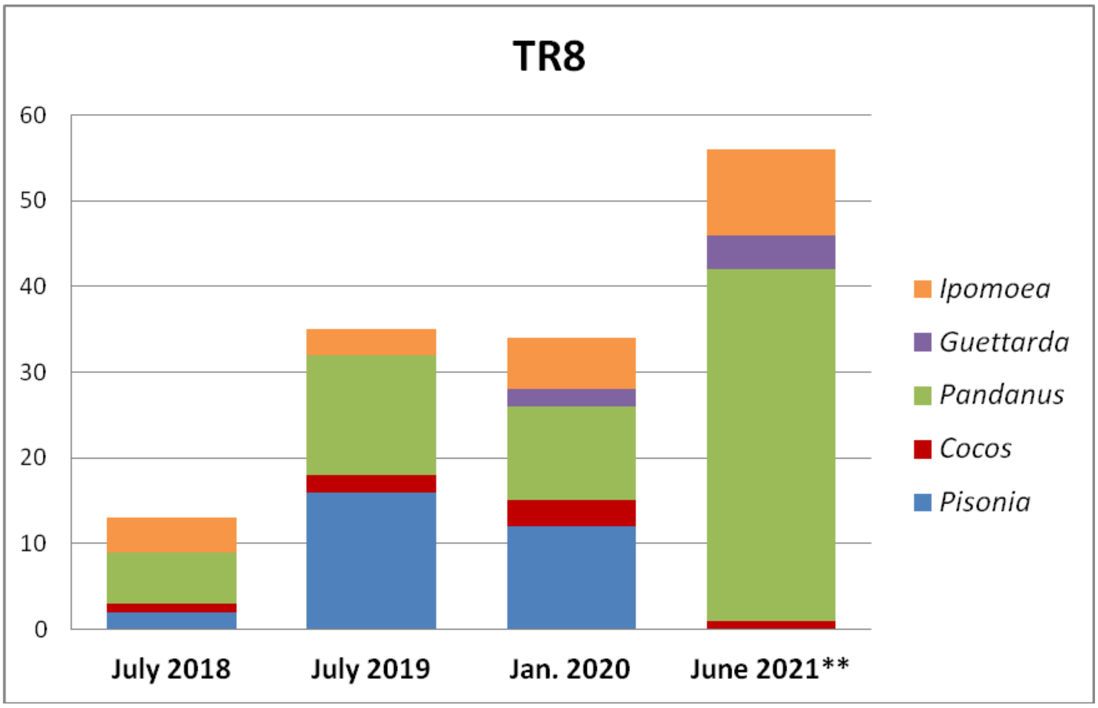
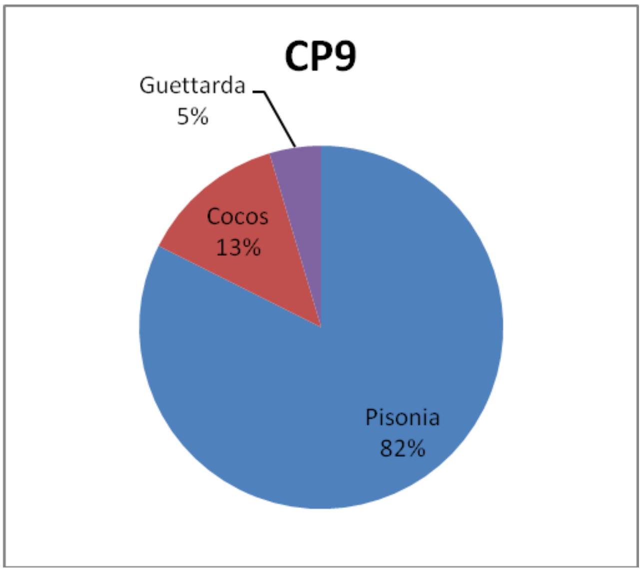


Figure 11. Forest composition and woody species cover (%BA) in circular plot CP9, and evolution of the seedlings number in the permanent transect TR9 between 2018 and 2021.



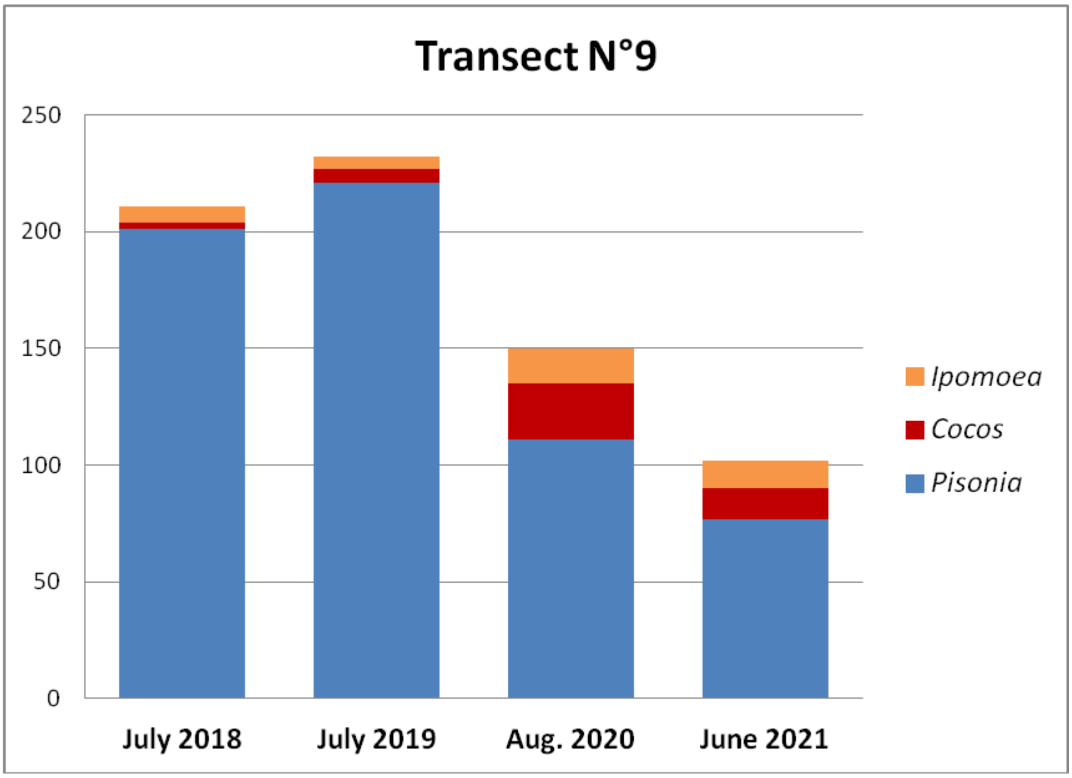
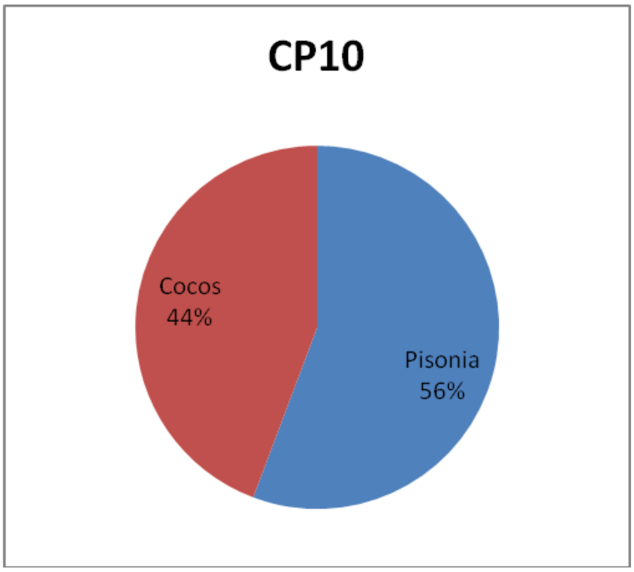
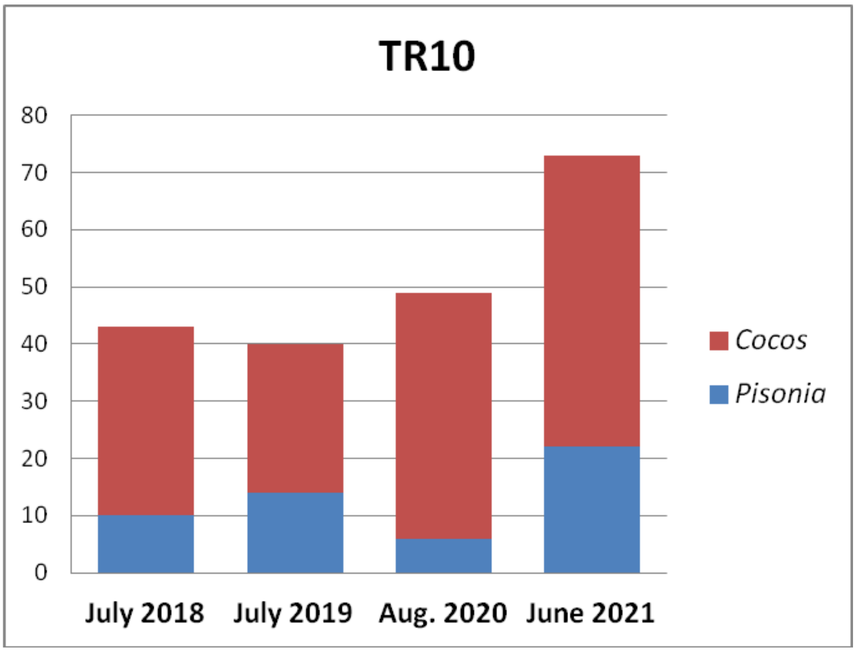


Figure 12. **Forest composition and woody species cover (%BA) in circular plot CP9, and evolution of the seedlings number in the permanent transect TR10 between 2018 and 2021.**



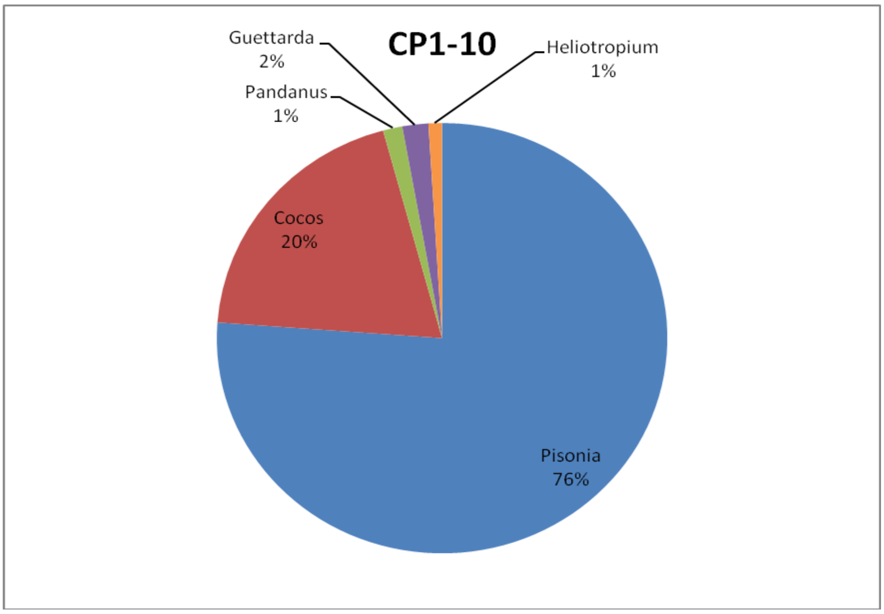


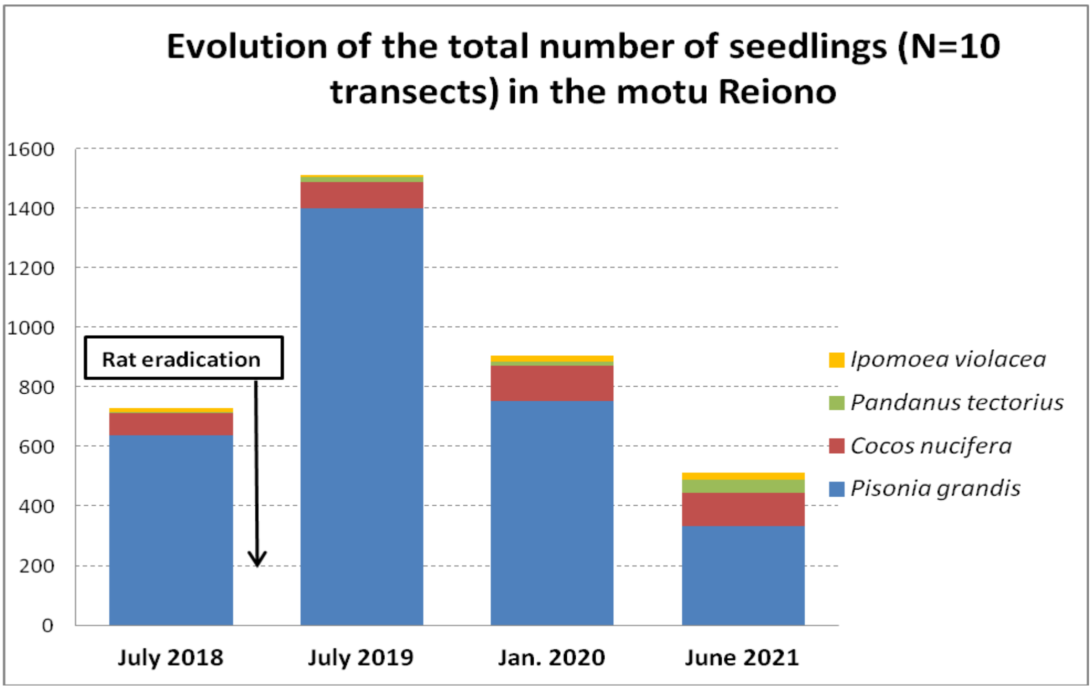
Conclusions and future prospects

Long-term monitoring by setting up permanent study plots is essential to study forest dynamics and understand ecosystem successional trajectories, especially after natural or anthropogenic disturbances, but also during ecological restoration efforts (e.g. weeding, herbivore exclusion, predator control). The 10 permanent transects installed on Motu Reiono in well-described forest types allowed us to monitor (mostly woody native) plant species recruitment before and after a rat eradication program over a four year period of time in a comprehensive way.

As previously documented in the vegetation study conducted after rat eradication in Palmyra atoll (WOLF *et al*., 2018), we observed a seedling increase of the native tree *Pisonia grandis*, but also *Pandanus tectorius* and *Guettarda speciosa* which fruits, seeds and/or seedlings are presumably eaten by rats. However, the total number of *Pisonia* seedlings has dramatically decreased three years after rat eradication, and found below its original level (**Fig. 13**).

Figure 13. Forest composition and woody species cover (%BA) in circular plots (CP1-10) and evolution of the seedling number in the 10 permanent transects (TR1-10) between 2018 and 2021.





This unexpected successional pattern might be explained by both abiotic and biotic factors (*e.g.* fruit, seed and seedling predation by rats and crabs). Natural disturbances such as treefall gaps and canopy opening caused by wind (*i.e.* more light in the understorey) may favoured the seedling recruitment of this light-demanding pioneer species whereas periodic flooding may destroy its seedlings, contrarily to *Pandanus*, a native tree species forming dense stands (especially in almost pristine uninhabited atolls, such as Morane in the Tuamotu-Gambier, unpub. data) which seem to be more adapted (and resilient) to changing environmental conditions.

Results in Palmyra have demonstrated a strong increase of *Cocos nucifera* seedlings and biomass five years after rat eradication (WOLF *et al.* 2018, MILLER-TER KUILE *et al.* 2021). The same trend is observed on Motu Reiono where there are also numerous fallen young coconuts in the transects which are no more eaten by rats. The removal of coconut trees, considered as an invasive species with detrimental impacts on atoll native forest ecosystem (YOUNG *et al.* 2010) should be considered as currently done in Palmyra (WEISS 2020), and in the other motus of Teti'aroa where future rat eradication is planned in August 2021.

In July 2021, we have set up 10 new transects on Motu Auroa (a small motu located on the north side of the atoll), and added to our seedling recruitment protocol a visual assessment of herbaceous plant cover (using six classes: 0-1%, >1-5%, >5-25%, >25-50%, >50-75%, and >75%) in order to monitor the potential changes in abundance of the creeping herb *Boerhavia tetrandra*, the succulent *Portulaca* cf. *oleracea*, and the terrestrial fern *Microsorum grossum*, which are present on the motu and might be also eaten by rats (and crabs).

We strongly recommend a more long-term monitoring of all these permanent transects and quadrats (at least for two more years on Motu Reiono), to have a more comprehensive view of atoll forest dynamics and successional trajectories after rat eradication.

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<u>Appendix 1:</u> Photos of study sites with seedlings recruitment (credit: J.-Y. MEYER©)

<u>Photo 1.</u> *Pisonia* dense forest (TR1): comparison between July 2018 (left) and June 2021 (right) with an increase of *Pisonia* seedlings.

<u>Photo 2.</u> *Pisonia* dense forest (TR3): comparison between July 2019 (left) and June 2021 (right).

Photo 3. *Cocos-Pisonia* mixed forest (TR4): comparison between July 2018 (left) and June 2021 (right) with an increase of coconut seedlings.

Photo 4. *Pandanus-Pisonia-Heliotropium* mixed forest (TR5): comparison between July 2019 (left) and June 2021 (right) after the passage of a high tide or strong swell.

Photo 5. *Pisonia* dense forest with *Cocos* (TR7) : comparaison between July 2019 (left) and June 2021 (right) after a tree fall gap.

Photo 6. *Pisonia-Cocos-Guettarda* mixed forest (TR9): comparaison between July 2018 (left) and August 2019 (right) with an increase of coconut seedlings.